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THE D-1 SATELLITE

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THE D-1 SATELLITE */3

The scheduled launching of the French test satellite D-1A, the first of the D-1 geodetic series placed into orbit by the 18-ton Diamant three-stage launch vehicle, is described in a Press release. A separate instrument capsule is to transmit telemetry data on operation in space of both booster and satellite, including temperature, voltage, and solar cell functioning. Conception, development, and pre-launch ground testing are reviewed, with detailed description of structural details and orbital parameters. The expected plus count after T-time, beyond separation of the satellite from the instrument capsule is given, and data work-up schedules are listed.

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I. INTRODUCTION

The first French technical research satellite, D-1A, constructed by the National Center for Space Studies (CNES), will be placed in orbit in the very near future, using the French launch vehicle "Diamant". The Society for Research and Development of Ballistic Rockets (SEREB) has been charged with supervision of the launch vehicle and the launching itself, under the auspices of the Ministerial Delegation for weapons (DMA). The launching is scheduled for February 10, 1966, at the Interservice Testing Center for special rockets (CIEES), from the French military launching base in Hammaguir (Algeria).

This will be the second time that a Diamant will be fired. It is known that on November 26, 1965, at the first test firing and under prescribed conditions, the Diamant No.1 functioned perfectly, proving that it is able to place a payload into orbit.

The D-1A will be the second satellite that the CNES has placed in orbit; in fact, the CNES also designed the first French scientific satellite, known as the FR-1 and successfully launched on December 6, 1965 from Vandenberg Base in California, with a Scout rocket.

The coming launching will initiate a new phase of the National Space Program, which will include the launching of research satellites of the CNES by the French launch vehicle Diamant. At present, three Diamant boosters have been ordered by the SEREB, in conformity with the CNES-DMA agreement of May 9, 1962. The three corresponding payloads constitute the D-1 program; they are designated, respectively, D-1A, D-1B, and D-1C. As stipulated in the agreement, these will be used for testing the operation of the launch vehicle; at the same time, they will provide for space testing of equipment of French manufacture, comprising the basic elements of space technology. Finally, these launchings will permit scientific exploitation of measurements, specifically in the field of geodesy. Some launchings within this program also will comprise the testing and further development of all French launching facilities for a satellite, obtaining its line of position in space, and establishing communication with the vehicle in orbit, facilities that belong to the DMA and CNES, respectively. /6

The payload of the Diamant No.2 will be 40 kg; the scheduled orbit will be 505 km at perigee, 2695 km at apogee, and will have an inclination of 34° to the Equator. The satellite D-1A itself weighs 19 kg. The satellite is fed by solar energy and its expected life is considerable; no doubt its lifetime will be limited only by possible failure of the onboard equipment. The remainder of the payload (instrument capsule) is to obtain measurements on the booster itself and on the insertion into orbit. This capsule, fed by batteries, will operate only for the required time, which is about 20 min.

The program of the satellites D-1 is placed under the auspices of the Satellite Division of the CNES. The person responsible for the satellite D-1A is J.-P.Guinard. The scientific mission of the satellites D-1 is the responsibility of J.-M.de Lamare. In fact, practically the entire personnel of the scientific and technical management of CNES has participated in the conception, realization, and testing of the satellites D-1 and will participate either in the launching itself or in their utilization.

II. DEFINITION OF THE SATELLITE

The D-1A, whose function is to provide space tests of basic elements of space technology, has been conceived for furnishing a maximum of data despite its low weight, intentionally limited to 20 kg. This extreme lightness in weight is not synonymous with simplicity; rather, it indicates the degree of technical refinement obtained.

At the inception of the project, at the beginning of 1963, not one of the equipment placed on board had been in existence in France. The entire instrumentation has been the result of research contracts and, later, of development contracts let to French industry. First the manufacturer and then the CNES subjected the equipment to numerous experiments and tests; it can be stated that, in the majority of cases, considerable technological progress has been made in the respective fields.

At the time, France had no high-output photovoltaic generators, no tight/7 rechargeable batteries, no low-consumption electronic circuits, no transmitters and no converters of the necessary high output under the requirements posed by weight and safety, no high-stability quartz clock, and no structures that, simultaneously, were rugged and light in weight.

This vast program, developed under the combined efforts of the CNES and numerous industrial firms, will find its culmination in the actual test of the D-1A under the rigorous conditions of space flight.

2.1 Structure

The satellite D-1A has the form of a cylinder of about 50 cm diameter and 20 cm height, whose two circular faces, both upper and lower, are closed off by a truncated-cone cap. The lower floor is provided with four rectangular articulated panels of 42 cm length and 21 cm width, carrying the solar batteries. To the upper cap, four telemetering and telecommunication antennas of about 75 cm height are mounted; another antenna of 20 cm length is installed along the longitudinal axis of the satellite. The height of the satellite, in orbital configuration, is 1.27 m and its overall diameter is 1.15 m.

The structure of the satellite is composed of a fixed central portion and of mobile portions which are represented by the solar panels, the antennas, and the connecting strip with the instrument capsule.

The fixed portion of the metal frame is basically composed of a central tube that supports the entire structure and transmits the thrust from the rocket to the satellite, as well as of a platform for carrying the electronic equipment, suspended by four tie rods from the central tube.

The central body is formed by a truncated cone, topped by a cylinder, all of which is made of machined magnesium. At the base, this central body diverges to permit contact with the third stage of the launch vehicle, and is used as support for the spring base for separation of the instrument capsule from the satellite.

The platform is designed in honeycomb structure. The periphery is provided with fittings to which the four solar panels are hinged, at the same point at /8 which the stay rods of the platform are attached. Thus, the latter also absorb the forces produced by deployment of the panels.

These two principal structural elements carry all secondary elements: the upper platform, the ferrule that closes the satellite off laterally, the lower fairing intended mainly to contribute to the thermal control of the satellite, the upper fairing carrying the antennas, and the cap that closes off the central tube at its upper part.

The mobile portions, exterior to the body of the satellite, raised difficult problems. The solar panels are folded upward while the satellite is within the nose cone of the rocket and thus overlap each other, forming a highly rigid pyramid. The panels are maintained in this position by four stretched metal cables which connect each panel to a central point of the cap. A pyrotechnic device frees the four cables at a prescribed instant; at this time, the solar panels will deploy under the effect of the centrifugal force. In orbital configuration, they are inclined by 45° to the satellite axis. The panels are freed only after a yo-yo system has reduced the velocity of rotation of the third rocket stage, to which the satellite is still attached over the instrument capsule. Thus, these panels deploy at a velocity of rotation of 30 rpm; the time of deployment is one second. The opening shock on the hinge fitting is damped by a flexible "sandwich" material, placed between the panel and the articulation strap.

The four swivel antennas for telemetering and remote control are mounted to the upper cap. Each antenna, weighing 90 gm, consists of a brass tube of 0.2 mm thickness and 505 mm length. These rigid tubes are articulated at their base, which permits an inclination toward the satellite axis while they are still within the cone of the third rocket stage.

The 400-mc antenna (second frequency for Doppler effect measurements) consists of a radiating rod, mounted along the longitudinal axis of the satellite.

Since the separation of the satellite from the instrument capsule takes place after deployment of the solar panels, it is of importance that the separation strip, connecting the two orbiting masses, will not damage the panels. The final design of the strip, after numerous tests, is of a rigid construction. /9
The strip consists of three parts, linked by three explosive bolts, which keep the strip squeezed between the satellite and the capsule during the entire launching period.

To permit proper separation, the three parts of the strip are rapidly ejected, far from the fixed portions. The expansion of a single helical spring imparts the necessary supplementary velocity to the satellite to have it move away a certain distance from the instrument capsule.

2.2 Stabilization and Equilibration

It is well known that, for accurately defining the direction of insertion into orbit of the satellite, the entire unit consisting of the empty second stage, the third stage, the instrument capsule, and the satellite is made to rotate at 270 rpm (4.5 rps) in a preselected direction, by the guiding system of the second stage. This latter then separates from the rest, and the third stage is fired. The satellite could be separated from the third stage, while conserving this rotational velocity; this was done in the A-1 satellite. However, this involves some risk at the instant of deployment of the appendages (solar panels and antennas) which are subjected to considerable centrifugal forces at this moment.

In the case of the D-1 satellite, it was decided to decelerate this rotation to a lower value of 30 rpm (half a turn per second) sufficient for maintaining the D-1 axis in a fixed position. Thus, the satellite behaves like a gyroscope in space. This deceleration is obtained by a so-called yo-yo system, which is mounted to the instrument capsule: Two masses, attached to an exterior hoop at diametrically opposed points, are attached to the extremity of bands wound on this hoop. At the proper instant, a timer fires a pyrotechnic system which frees the masses. Under the effect of centrifugal force, these masses move away from the body of the capsule and unwind the bands, thus increasing the moment of inertia of the entire assembly and reducing the rotational speed at a corresponding ratio (just as a skater extends his arms to stop). The other extremity of the bands is not fixed but loosely retained in a notch or slot, so that it is freed at the end of deployment. The entire operation takes only 0.26 sec and exerts a considerable force on the bands and on the capsule.

The deceleration system obviously depends on the moments of inertia of /10 the system, before and after fallaway of the yo-yo. Accurate measurements are made during the tests.

On the other hand, to have the satellite behave as a regular gyro, it must be balanced about its axis of rotation; the corresponding static and dynamic balancing operations also form part of the test program. For this, counter-weights are added, in a manner similar to that used in balancing an automobile wheel, except much more accurately.

Naturally, the unavoidable (although weak) effect of perturbation couples exerted on the orbit of the D-1 (aerodynamic drag, interaction between the earth's magnetic field and the stray currents on board the satellite or with the magnetized masses present on board) will necessarily lead to a precession, i.e., a slow oscillation of the satellite axis about the initial axis of rotation. To keep the system stable, the moment of inertia of the desired axis of rotation must be greater than that obtained with respect to any other axis (the ideal form, as for a spinning top, is that of a flat coil). This condition has played an important role in determining the position of the solar panels after deployment.

On the other hand, the amount of magnetic materials has been reduced to a minimum, and the total residual magnetic moment of the satellite was measured carefully in a specialized laboratory.

2.3 Electronic Equipment

Most of the electronic instruments were designed in the form of rectangular modules of identical dimensions (sides of 122 or 200 mm; height of 33 mm). Twelve modules in all are placed inside the satellite, mounted to the lower platform in groups of three. Each module consists of a metal casing made of aluminum alloy, housing a certain electronic instrument, and accurately kept in place by means of plastic foam foamed in situ and entirely filling the box.

It has been left to the discretion of each industrial contractor to choose the technology with which he is most familiar. For this reason, some of the contractors used printed circuits in which they were most experienced, while /11 others preferred soldered circuits.

2.4 Data Transmission

Over the entire duration of the flight, the telemetering equipment transmits back to earth not only the results of technological experiments on the solar cells but also a series of data on operation of the equipment in space environment.

This data transmission is quite complete, including temperature, voltage, and current measurements. Each datum is transmitted once by telemetry cycle.

2.4.1 Temperature Measurements

The following measurements were taken:

- temperature of the solar panels;
- temperature of the batteries;
- temperature of the central casing of the high-stability oscillator;
- temperature of the satellite structure.

The sensors comprise thermistors pasted to the elements of which the temperature is to be measured; the accuracy is within $+3^{\circ}C$.

2.4.2 Voltage Measurements

The following measurements were taken:

voltage at the terminals of the four battery elements and the total output voltage of the battery;

voltage at the terminals of the overcharge control;

voltage at the terminals of the two converters;

voltage of the thermostat of the high-stability oscillator; /12

voltage of the automatic gain control of the 150 and 400-mc transmitters;

voltage at the terminals of the remote-control receiver.

These measurements are made possible by the use of resistive voltage dividers which prevent a possible short circuit in the telemetry system from interfering with the feed circuits themselves. The accuracy of the pickups is ±1%.

2.4.3 Intensity Measurements

The following measurements are made:

current intensity of the battery;

current intensity of the solar generator.

The overall accuracy of the pickup and of the amplifier is ±5%.

2.5 Thermal Control

In space, the satellite exchanges thermal energy only in the form of radiation. Energy is received from the sun but also from the earth which behaves, roughly, as a black body at about -20°C. This energy is imparted to the satellite either directly when some areas of its surface are illuminated, or indirectly when the light is reflected or diffused by the earth, by the high atmosphere, and by clouds, or else when the solar panels are deployed and furnish electric current.

The satellite, in turn, emits a characteristic thermal radiation; in addition, the satellite must dissipate the excess energy that it might receive (in the form of the Joule effect) from the interior electric circuits when these are operating or from the solar panels when their illumination is maximal.

Depending on whether the exchange balance is positive or negative, the /13 temperature of the satellite will rise or drop; the problem of thermal control consists in maintaining this temperature, in all possible cases, within limits selected in advance. In general, these limits are imposed by the electronic equipment which operate satisfactorily between approximately -10° and $+40^{\circ}C$.

The satellite D-1 also contains an oscillator whose quartz crystal is maintained at a temperature of $60^{\circ}C$ to within a few thousandths of a degree, an accuracy that can be obtained only by an active control, using an electric control current sent through a filament resistance. This latter must discharge continuously and thus tap a certain electric power from the battery (0.650 w).

It is impossible to use the same technique for the entire satellite. The required power would necessitate a considerable increase in the surface covered by the solar cells and an excessive increase in both bulk and weight of the battery. Therefore, a passive thermal control is used for the D-1 satellite: The surfaces of the various materials do not absorb solar radiation in the same manner and do not emit as much in the infrared. This makes it possible to select, from available types of coatings, those that permit an equilibration of the heat exchange balance.

The selection of the coating proceeded on the basis of experimental studies and theoretical calculations. Here, it was primarily a question of estimating the heat exchange balance between the satellite and the sun, in all possible attitudes of the satellite in orbit. For example, if the D-1 is spin-stabilized, the plane of its orbit will vary with respect to the plane of the ecliptic because of the earth's rotation. On the other hand, depending on the time of year and the hour of launch, the satellite may either pass through the earth's shadow for a more or less long portion of its period of revolution or may remain constantly illuminated by the sun. Therefore, the extreme cases must be studied from the temperature viewpoint, i.e., the case in which the satellite is constantly illuminated by the sun and the case in which it is less illuminated, taking into consideration the three possible principal orientations that the satellite can have in orbit, i.e., six possible cases.

In addition, three types of heat exchange must be considered:

The heat that an element of surface receives from the sun and that which it gives off to the ambient medium, for a given attitude and orbit.

The heat that the satellite exchanges by radiation and conduction with /14 the instruments inside its structure; for better studying and controlling this predominantly radiant exchange, the inside of the satellite is painted black.

The radiant exchange between satellite and ambient medium, as a function of the coatings of the outer surfaces.

For the D-1 satellite, four types of coatings were selected: white and black paint, aluminum and gold metal plating. An elementary calculation indicates that, testing each one of these coatings on any of the surfaces involved, a total of 1024 different cases will result. A program of optimization of coatings restricts this choice to about 30 cases; the selection is then subjected to technological considerations for defining the coating to be preferred. The technological considerations that guide this choice comprise: definition of the coefficients of absorption and emission of the coatings, degree of independence from environmental conditions such as heat cycles, exposure to ultraviolet rays, aging, etc.

After this, the characteristics of the selected coatings are determined by means of a space simulator and a solar simulator. This will permit a comparison of these results with the experimental data transmitted by telemetry from the D-1 satellite in orbit, which no doubt will provide an even better control of the heat exchange of future satellites with the ambient medium.

However, the satellite will reach its permanent thermal regime only after four or five orbits. During this first orbital period, thermal control is even more important since it lays the foundation for a satisfactory long-term operation of the electronic or scientific instrumentation. Between launching and insertion into orbit, the satellite is subject to a series of extreme thermal stresses.

If it were attached to the nose cone of the third stage of the rocket without special precautions, the satellite D-1 would be subject to air friction from the moment of liftoff. As is conventional for all satellites that are designed to travel in vacuum, the shape of the D-1 has been designed without regard to aerodynamics. Therefore, the satellite is protected by a nose in the form of an ogive which will be jettisoned at the proper moment.

The rocket lifts off at progressive acceleration, in an atmosphere which becomes increasingly rarefied. The friction of the air molecules gradually /15
heats the outer wall of the ogive, while the capsule, inside the nose cone, is heated less rapidly. Solid particles or molecules produced by the degassing of

the ogive may adhere to the coating of the satellite and thus modify its thermo-optical characteristics.

As soon as the dense layers of the atmosphere have been traversed, the ogive represents only useless ballast which must be jettisoned as soon as possible. At this time, the satellite, because of its velocity, is subject to considerable residual aerodynamic heating. The satellite still remains attached to the instrument capsule which, like the satellite itself, is subject to radiations from the sun, the earth, and the albedo and which, in addition, is heated by the dissipation of the heat liberated by the internal circuits, and by conduction, across the last stage, of the heat liberated from the duct at 2000°C.

During the launch and up to the instant at which the D-1 is separated from the instrument capsule and starts its autonomous existence, the temperature level must be maintained within the limits defined in advance. A computation program will yield data on the heating of the satellite within the ogive and, after the ogive has been jettisoned, on the aerodynamic heating. From this, the instant at which the ogive must be cast off can be defined. We found that the antenna platform reaches a temperature of 140°C, if the ogive is opened 120 sec after firing of the first stage, 75°C if it is opened at 125 sec, and only 33°C if it is opened after 130 sec.

These theoretical predictions were verified by intersection with the flight data furnished by Rubis No.1*, which permitted testing the assembly consisting of the third stage, the instrument capsule, the satellite, and the ogive, by a test firing of the mockup to 2000 km altitude.

III. MANUFACTURING AND TESTING

The tests are intended to prove to the manufacturer that the satellite will

* See La Recherche Spatiale, Vol.IV, No.8-9, p.13.

function as predicted in space, after having survived the rigors of launching. All elements of the D-1 individually, and the entire satellite, were subjected to acceleration and vibration tests simulating the conditions of launch, as well as to heat and cold tests, vacuum and atmospheric tests simulating the basic conditions of orbital "life". The totality of these conditions is known as /16 "space environment". Extremely strict rules have been established and applied to all stages of manufacture. These rules can be defined as follows:

With respect to the cost of manufacture and launching of a given satellite, it is not so much a question of developing a new model by subjecting numerous identical units to tests on the test stand, as is done for less costly components or even for automobiles intended for wide distribution. Rather, the development of a satellite type is separated from the actual tests for each single unit. For this, several satellites are constructed. In the case of the D-1 satellite, individual subcontractors first designed a piece of equipment that met all functional requirements within the prescribed temperature range, disregarding for the time being the bulk requirement and the mechanical testing conditions. This so-called "preliminary model" was used for testing the principal characteristics of the circuits.

A new piece of equipment, known as the "model", was then manufactured under prescribed conditions; for the electronic part, this meant that it had to be installed in a module casing and embedded in rigid plastic foam. This model was then "qualified", i.e., subjected to vibration tests, thermal and cryogenic tests, vacuum tests, level tests, temperature tests, and lifetimes longer than those expected in flight. These tests revealed a certain number of defects and failures which were eliminated, after which the tests were repeated. The entire "model" equipment was then assembled (this is occasionally called "integrated") into a "model" satellite, which was not subjected to environmental tests but was used for numerous auxiliary operations such as study of compatibility with the launch vehicle.

To gain time, other "model" satellites, in a more or less final state, were manufactured; these were used for certain specific tests. Thus, a "radioelectric model" is in existence which was used for studying the radiating elements; another type was a "handling model" representing a regular simulator in which manipulation of the costly satellite could be trained; still another type was a "study model of the solar generator" which permitted full-scale tests on the effect of shadows thrown by the antennas on the solar panels and on the mutual shadowing of the panels themselves.

Finally, the "model" structure, loaded with facsimile equipment, was /17
launched on a suborbital flight by a Rubis rocket on June 5, 1965 from Hammaguir. This launching proved satisfactory structural resistance to real vibrations, making it also possible to test the sequence of antenna and panel deployment under conditions of weightlessness as they are impossible to reproduce in the laboratory. The "equipment models" terminated the development phase.

This was followed by the manufacture of "flight models" of equipment and structure, which were produced in three copies. The first, representing the prototype, was subjected to all high-level tests known as qualification tests. Only a few defects were discovered. These were carefully analyzed; it was found that they corresponded to failures or defects of individual components and did not involve the conception of the equipment as such. Incidentally, none of the detected defects would have led to complete operational failure of the satellite whose design permits tolerance of a certain number of failures (duplicate circuits, standby converters, standby telemetry equipment, etc.). After the necessary repairs, the tests were resumed, resulting finally in a system that had "met" all qualification tests. Thus, since the satellite now satisfied all conditions it could have been launched. However, since it was feared that the structure was "fatigued" from the numerous tests, it was preferred not to run this risk. The two other "flight model" satellites, D-1A and D-1B, had been subjected only to leveling and endurance tests sufficient for proving conformity of the satellite with the prototype or, in the negative case, to locate individual defective components or circuit elements (solderings). An attempt was made to trace the complete history of the tests; for this, all equipment was delivered by the various manufacturers without having been subjected to environmental testing. These acceptance tests revealed no significant failures.

Such details are given here merely to demonstrate the extent of the complexity of problems associated with the manufacture of the satellite, after the design and performance problems have been solved which, in themselves, constitute still another aspect of the difficulties encountered.

To perform these tests, the CNES has erected numerous facilities for simulation of space environment in its Center at Brétigny. These facilities are used directly in the tests for which the CNES is responsible but are also at /18 the disposition of industrial firms on request.

The main equipment of this laboratory comprises the following:

Four vibration exciters, with a power ranging from 2.7 to 4.5 tons.

A large cylindrical simulator capable of subjecting a satellite of about hundred kilogram weight and 1 m diameter, to conditions of space vacuum in the presence of solar radiation. A vacuum of 3×10^{-8} torr can be reached within 10 hrs. A double-wall internal screen, of 3 m diameter and 3 m length, can be brought from -170° to $+100^{\circ}C$ by circulating gaseous nitrogen. This powerful equipment was designed for long-term tests with high reliability; the apparatus has been in satisfactory operation since September 1965 and has been used for as long as 2 - 3 weeks without major incident, in five overall-test series with the prototypes and flight models of the FR-1 and D-1 units.

Several simulators of smaller dimensions, ranging from 70 dm^3 to 1 m^3, permitting vacuum tests on various types of equipment, at temperatures varying from -100° to $+100^{\circ}C$.

Five temperature chambers, one of which has a capacity of 8 m^3, permitting tests from $-100^{\circ}C$ to $+100^{\circ}C$ at atmospheric pressure.

One centrifuge for testing the equipment under static acceleration; the acceleration tests for the full-scale satellites were made in the large centrifuge (whose cabin can accommodate a pilot) at the Test Flight Center.

IV. ONBOARD POWER

The instruments of the satellite are fed by a power generator system, comprising the following:

A solar generator and a battery, supplying electricity to the satellite equipment. The solar generator is composed of four panels, attached to the body of the satellite and carrying the solar cells that convert light energy into /19 electric energy. Since the satellite is not always illuminated, the solar generator, during the period of illumination, charges a battery which feeds the instruments, whether the satellite is illuminated by the sun or whether it is within the earth's shadow. Thus, the battery is charged during the periods of illumination (70 min) and discharged during the periods of darkness (50 min).

Two converters that distribute and regulate the necessary electric current for operation of each individual piece of equipment, at the required voltage.

A standby protection system for the battery, which prevents its discharge as well as an overcharge.

4.1 Solar Generator

The solar generator is composed of four panels to which a total of 2304 photovoltaic cells is mounted.

These cells, manufactured in France, are equal in quality to those used in US satellites (same power output). They are of the n-p silicon type, with a length of 2 cm, a width of 1 cm, and a thickness of 0.5 cm.

The cells are protected from bombardment by micrometeorites and particle radiation by a thin glass sheet of 150 μ thickness. These glass panes are provided with a blue filter on their inner surface, which limits the transmission to spectral bands useful for the photovoltaic conversion. On the outer surface, the panes are covered with an antireflection coating.

Each panel, on each of its two faces, carries nine small plates of 32 cells connected in series, with the eight faces of the panels connected in parallel. The connections between the plates are made by printed circuits. Two thermistors are pasted to each face of the panels, for determining the temperature. A diode, inserted between the positive pole of each plate and the positive pole of each panel, prevents charging of the nonilluminated plates by the illuminated plates.

The solar generator was designed to meet a special requirement, differing/20 - for example - from that of the project FR-1 where maximum power was the prime requisite. In the D-1A satellite, it is desired to supply power to the instruments independent of the time of launching (season or hour), so as to prevent conditions that a launch vehicle would have difficulty to satisfy during a test series. A satellite of spherical shape satisfactorily meets these requirements; however, the nose cone of the Diamant is too pointed to accommodate a spherical satellite of a sufficiently high power. Therefore, the solution selected was to use panels; an attempt was made to optimize the angle of these panels with respect to the axis of the satellite, in order to satisfy the above condition. It was found in the laboratory that the optimum inclination of the panels is 55°. The actually selected inclination differs slightly from this (45°), so as to increase the moment of inertia of the satellite about its longitudinal axis with respect to its other two moments of lateral inertia. Under these conditions, the average available power will always be above or equal to 5 w.

4.2 Battery and Power Distribution

The satellite is equipped with a single battery, comprising eight tight nickel-cadmium elements connected in series, with a rated capacity of 3.5 amp-hr. The charging voltage is 11 v on the average, and the mean discharging voltage is 9 v. This battery and its elements, on request by the CNES, were specifically designed for use on the satellite and their development was given special care.

The consumption of the satellite instrumentation is 2.8 w when the Doppler emitters are not operating. When these devices are in the on-position, the power consumption reaches 5.2 w for a cycle of 16 min per orbit of 120 min, on remote-control instruction.

The battery is able to function at temperatures ranging from -10° to $+40^\circ$C, but beyond this its characteristics fluctuate strongly. The temperatures reached and the current passing through the battery are transmitted to the ground by telemetering.

The permanent and regular onboard distribution of electricity is ensured by a permanent converter-regulator. The Doppler emitters are directly fed from the battery terminals.

4.3 Protective System for the Battery /21

Two devices have the function of maintaining the battery in satisfactory operating condition:

A charge regulator which limits the charging current and the voltage at the terminals of the battery, taking the temperature of the latter into consideration. Any possible power excess is conducted to an external dissipation circuit, consisting of three power transistors, mounted to the outside of the satellite.

A discharge protector, which constantly monitors the voltage at the battery terminals. As soon as this voltage drops below 8 v, the feed to the main converter is interrupted. At this time, the solar generator is used only for feeding and recharging the battery. The feeding system for the pieces of equipment is automatically cut in after 10 hrs. However, in the case of failure of the protective system, reconnection of the feed system can be ordered by remote control. For this, during the recharging cycle, power supply to the timer which counts the 10 hours as well as to the telemetry receiver is ensured by a secondary converter.

4.4 Data on the Solar Cells

The solar cells are photodiodes with semiconductors whose active substrate (silicon) is doped with p-impurities, into which a relatively shallow junction of n-impurities is diffused. These diodes absorb the light photons and convert them into electric energy. The great usefulness of solar cells lies in the fact that they supply electricity to all pieces of satellite equipment and that the lifetime of the satellite depends on their efficiency. Thus, the satellites will "die" as soon as the output of the cells reduces to a point where they no longer furnish a sufficient amount of electric current.

Independent of the characteristics of the totality of cells comprising a solar generator, it was found advisable to make studies on the degradation of solar cells when subjected to a hostile environment; the procedure was to mount other cells of the same type on a small plane plate, attached to the body of the satellite, for the following purpose:

observe the effect of charged particles (electrons, protons) of the /22
Van Allen belts on their electric behavior;

determine the attitude of the satellite relative to the sun.

The plate carries three groups of cells, comprising the following:

First group: five stripped cells (without filter).

Second group: five cells individually protected by a glass window of 150 μ thickness and provided with an interference filter.

Third group: cells, pre-irradiated in the laboratory with a dose of 10^{16} electrons of 1 Mev.

A study of the effect of particle bombardment of the two first groups is performed by comparing the voltages at their terminals with the voltage at the terminals of the third group, used as reference.

In fact, the sensitivity for the semiconductor materials used decreases exponentially as a function of the received dose. The voltage fluctuation at the terminals of the reference cells will thus be negligible with respect to that produced by particle bombardment in the van de Graaf accelerator at the Polytechnic Institute, where these cells were subjected to a pre-irradiation at a very high dose.

Finally, measuring the voltage of the reference cells will permit a rough reconstruction of the satellite attitude with respect to the sun.

V. TELEMETRY AND REMOTE CONTROL

The satellite D-1 is equipped with a system of telemetering instruments and a system of remote control devices. The telemetering transmitter operates on a frequency of 136.980 mc; the remote control commands are transmitted to the satellite on a frequency band of 122.9 mc.

The telemetering equipment operates continuously, except for the period /23
of down-time of all equipment in the case that the battery needs recharging. The adopted modulation (in phase) permits using the carrier as signal and thus tracking of the satellite. The system of remote control transmits the command to start feeding the transmitter for the geodesy experiments.

The transmission of signals as well as their reception proceeds over a swivel antenna array, consisting of four quarter-wave whip antennas, hinged to the upper cap of the satellite and symmetric with the axis of rotation of the satellite.

The telemetry and remote-control network that picks up the emissions from the satellites and sends commands to it, will be the French Iris network, entirely equipped with French materiel, comprising five stations located in Brétigny (France), Hammaguir (Algeria), Ouagadougou (Upper Volta), Brazzaville (Congo), and Prétoria (South Africa). The geographical position of these five stations was selected in consideration of the launchings of satellites whose orbits will be only slightly inclined to the Equator.

5.1 Telemetry System

For the D-1 satellite telemetry, the CNES selected the PFM (pulse-frequency modulation) system, designed and developed at Goddard Space Flight Center of NASA by R.Rochelle and coworkers, used successfully in the Explorer satellites (particularly, the Imps) as well as the two Ariel, etc. This system is close to ideal for small satellites, has a very low consumption, and permits communication under exceptional conditions and over extreme distances. Conversely, its capacity in number of samplings transmitted per second is somewhat limited for certain applications.

The principle of encoding the data is as follows: Each of the channels is frequency-modulated (by a voltage-frequency converter), and the channels are then time-division multiplexed. The multiplex train, sent to the transmitter, appears as a series of short sinusoidal trains, separated by intervals. The "format" used for the D-1 comprises 32 samples, two of which are subject to /24 fixed frequencies used for detecting the beginning of the format and the synchronization; thus, 30 measuring channels exist. Each of the samples has a duration of 1/50 of a second.

The PFM train modulates in phase a transmitter, controlled by a quartz crystal and radiating a power of 250 mw at a consumption of less than 1 w. Finally, it should be recalled that a diplexer couples the telemetry transmitter at 136 mc and the scientific transmitter at 150 mc to the same antenna.

5.2 Remote Control System

The remote-control system permits transmitting two different commands to the satellite:

The command "start experiment" which initiates feeding of the scientific instruments.

The command "standby" which interrupts feeding of the scientific transmitters, while starting the general feeding of all pieces of equipment. This constitutes a possibility for intervening in the case of failure of the automatic battery discharge monitor.

The remote control system is composed of three elements:

a receiver with a single reception frequency in the 122.9 mc band, of the superheterodyne type;

a decoder, connected to the output of the receiver, which detects the modulation code and interprets the received command;

a programer "operation - standby", which receives the two commands from the decoder on its two separate inputs.

Protection from premature start is ensured by the encoding system of the "address - execution" type. In fact, the command is only executed if the first signal "address" which opens one gate is followed, after a predetermined time while the gate is still open, by a second signal "execution" which constitutes the actual command and is thus sent to the programer.

VI. SCIENTIFIC GEODESY PROGRAM OF THE SATELLITE D-1 /25

From the beginning of the space era, French scientists have been interested in space geodesy; since 1959, the Observatories of Meudon, Besançon, Bordeaux, and Strasbourg have been tracking satellites by optical methods; specifically, they obtained photographs of artificial satellites which permitted a better definition of the causes and the extent of deformation of the orbits of such satellites. In 1964, the IGN (National Geographic Institute), in collaboration with the CNES, has started a program of geodesic links by satellites: The satellite Echo was photographed simultaneously against the background of stars by five stations (three in France and two in Algeria); this permitted the first triangulations by satellites.

In January 1965, the Aeronomy Department of the CNRS (National Scientific Research Center), at the Observatory of Haute-Provence, made the first French experiment with an American satellite, the Explorer XXII, in which a laser beam was reflected from a space vehicle. The accuracy of distance measuring (DM) reached 5×10^{-6}.

The geodesic program, scheduled for the three D-1 satellites, will permit a continuation of these studies. The program comprises the first French development of geodesic equipment on board a satellite: The D-1A and D-1B satellites will emit waves of high frequency stability, by means of which measurements of the Doppler effect will be made, permitting a calculation of the radial velocity of the satellites. The last satellite of the series, the D-1C, will be equipped also with prisms that reflect a laser beam emitted by ground stations, in which the time required for the round trip of the light will yield an accurate measure of the distance of the satellite from the station.

6.1 Space Geodesy

Geodesy is a science which attempts to determine, on the one hand, the form and structure of the earth by measuring the distance separating two points on the surface of the globe (geometric geodesy) and, on the other hand, by measuring the intensity and fluctuations of the terrestrial gravitational field /26 (gravimetric geodesy).

Over a number of years, launchings of artificial earth satellites have resulted in considerable progress of our knowledge of geodesy. In fact, the position fixing of a given satellite with respect to the stars whose position is accurately known within the system of celestial coordinates, permits calculating the celestial coordinates of the satellite. If, in addition, the position of three ground stations is known, it is possible to construct an accurately defined reference trihedron, whose base triangle has the imaginary lines joining the three stations two-by-two as sides, with the vertices being the satellite. This makes it possible to calculate the geographic coordinates of another point on the earth's surface, located at a reasonable distance from the three stations, by determining the position of the point with respect to the reference trihedron and thus connecting this point with the geodetic network of the three stations.

For this, two experimental methods can be used:

Either, the satellite can be photographed against the background of stars from three ground stations whose coordinates are known within a certain geodetic network, which permits fixing the instantaneous position of the satellite in orbit, relative to the stars; in this case, the position of a fourth ground station can be defined if only the angle of sight of this latter station is known which, in its turn, had photographed the satellite at the same instant as the other stations. Step-by-step, the position of the various points in a given geodetic network is thus determined.

A second method consists in fixing the position of the satellite from three known stations, but this time by simultaneously measuring the distances separating these stations from the satellite. The greatest accuracy is actually obtained by measuring the distances with the aid of a laser beam. It is then sufficient to measure the time required for the return trip of the light from the station to the satellite. Since the position of the satellite is thus defined relative to the known position of the three stations, it is possible - as before - to define the position of a fourth station which also sights the satellite at the same instant, using a laser beam.

Successive determinations of the instantaneous position of a satellite in orbit are used not only for measuring the distance separating two points on /27 the surface of the earth. In addition, an accurate definition of the orbit of a given satellite also gives a possibility of determining the deformation of this orbit in space and time, principally under the influence of variations and fluctuations of the terrestrial gravitational field, of which an actual chart can thus be plotted.

6.2 Geodesy Experiments of the Satellite D-1A

Two types of geodetic experiments will be attempted with the D-1A satellite:

In the first, use is made of the Doppler-Fizeau effect, by means of two special receiving stations that pick up the radioelectric waves of stable frequency emitted by the satellite.

In the second, the satellite will be photographed from one and, if possible, from several observatories.

It is well possible that, for the first satellite, D-1A, merely an attempt will be made to determine the satellite orbit by three different methods, so as to obtain the same information from these three procedures which will facilitate a comparison of their respective accuracy:

Primarily, the distance of the satellite from the ground and the direction in which the satellite is located will be determined by interferometer measurements, made by means of antennas from the "Diane" tracking system.

Secondly, the Doppler measurements will yield the radial velocity of the satellite and its time rate of change.

Thirdly, the photographs of the satellite against the background of stars will permit fixing its position in the system of celestial coordinates.

These geodesy and trajectography experiments will be made in collaboration with the Paris Observatory, the National Geographic Institute (IGN), the Bureau of Longitudes, and the French Navy; J.Kovalevsky, of the Bureau of Longitudes, will be charged with coordination of the entire program.

6.2.1 Doppler Effect Detection: Experimental Principle /28

When a moving body emits a continuous wave, the frequency of this wave, measured at a fixed point, is modified. This is known as the Doppler effect (the whistle of a locomotive at great velocity appears to change its tone, etc.). The phenomenon is the same for electromagnetic waves. The variation in frequency is proportional to the ratio of the relative velocity of the moving body with respect to the fixed point to the velocity of propagation of the wave. For a radioelectric wave, traveling at 300,000 km/sec, and for a satellite whose velocity is of the order of 7 km/sec, it is obvious that, even under the most favoring conditions, the variation in frequency will be negligible $\left(\frac{7}{300{,}000} = 2.3 \times 10^{-5}\right)$. For a wave at 136 mc, the variation will be $136 \times 2.3 \times 10^{-5} = 3$ kc.

This variation, although extremely slight, is accurately measurable. If the velocity of the above-mentioned satellite is to be determined from measuring the Doppler effect, for example with an accuracy of one thousandth, it is necessary that the frequency of emission on board the satellite is defined to within

2.3×10^{-8}. In practical application, the accuracy of Doppler measurements depends directly on the stability of the onboard oscillator, which therefore is to be optimized as much as possible. In fact, the frequencies are measured with respect to a reference oscillator on the ground, which can be a regular observatory clock since there is no limit placed on bulk, weight, or power. The oscillator, designed for the D-1 satellite, has a stability better than 2×10^{-8} over the entire duration of one passage (15 min) and under the relatively rigorous temperature conditions expected on board the satellite. Such a stability is equivalent to a variation of one second in 70 years. The oscillator constitutes a small quartz clock, thermostated with extreme care. For obtaining the desired stability, the temperature of the quartz must not vary more than a few thousandths of a degree.

In practical application, the ionosphere disturbs the measurements since, for too low a frequency, the radioelectric waves do not propagate at exactly the speed of light. This must be taken into consideration when calculating the true velocity relative to the satellite. It is conceivable to use a high emission frequency, but the technological difficulties are considerable in this /29
case. Therefore, it is preferred to use a method previously applied by American geodesic satellites, such as the Beacon Explorer, Transit, Geos; two frequencies, rigorous multiples of each other, are used here. It is demonstrated that, in this case, the calculations are considerably simplified and that, with satisfactory approximation, the ionospheric perturbation can be eliminated. A very narrow frequency band, in the vicinity of 150 and 400 mc, has been assigned specifically for this usage by the International Telecommunications Union. In the case of the D-1 satellite, the oscillator, common to the two transmitters, oscillates at 4.999 mc. By frequency multiplication, an operation that can be

performed without error, frequencies of 149.70 and 399.920 mc can be generated. Each of the transmitters radiates a frequency of 100 mw over an appropriate antenna. For a frequency close to 150 mc, a swivel platform is used which serves simultaneously for telemetering and remote control. For a frequency close to 400 mc, a special aerial is provided. In the case of the D-1 satellite, these transmitters are started only by remote-control commands from the ground. They automatically stop transmitting after 16 min.

It is possible that, in later flights, the launch window can be so selected that the satellite will receive sufficient insolation. This will produce sufficient energy to ensure continuous operation of these transmitters. In all these cases, the oscillator and its thermostat will remain connected, since an operation of several hours is necessary before thermal equilibrium to within a thousandth of a degree can be obtained.

On the ground, the transmissions are received by special antennas, and the frequencies are measured with respect to the base clock of the station. The two Doppler receiving stations, operating on the two frequencies of 150 and 400 mc, are erected at Beirut and near the Nice Observatory. Special receivers were installed by the CNES in its Beirut station. The other station belongs to the Technical Construction Service and to the Naval Forces.

6.2.2 Optical Tracking

The measurements of the Doppler effect are complemented by data obtained from photographs of the satellite D-1, which will be taken from the optical station at Nice, a branch of the Paris Observatory, under the direct responsibility of P.Muller. However, the optical observations will always remain more arbi- /30
trary than measurements of the radioelectric Doppler effect, since the former

depend on favorable meteorological conditions; on the other hand, the satellites will be at the limit of visibility of the camera used.

It would be of considerable interest to install a Doppler station close to the Nice Observatory, since radio and optical observations could be made at the same instant, during passage of the satellite. These will be the only observations permitting a determination of the orbital elements of the satellite, at the same instant and by two different methods. These will also be the only observations permitting a calculation of the position of a given station, when knowing the position of two other stations or - rather - a verification by calculation of the known position of a given station, starting from the known position of two other stations.

Each station will have facilities for receiving hour signals emitted by the National Bureau of Standards since, for interpreting the results, it is indispensable to know the position of the satellite at a precise instant as a function of one and the same time reference, which must be known within about one millisecond, namely, Universal Time.

It is expected that the complete processing of all data collected in this manner will require about one and a half years' work. The results of the measurements and observations will be used for various purposes:

The Mathematics Department of the CNES will be charged with calculating the ephemerides. An attempt will be made to define the orbit of the satellite in the European geodetic system, based on a simplified model of the terrestrial gravitational field and on the approximate positions of various stations. These calculations of trajectography will be made by the Center at Brétigny as they receive the interferometer and Doppler data; it will not be possible to keep track of the optical observations.

The Bureau of Longitudes and the Meudon Observatory will have the task of determining the orbital parameters of the satellite, from radioelectric data, from optical observations and - in the case of the D-1C satellite - from laser data. This will permit a comparison of the accuracy obtained with each of these methods.

In addition, the information coming from an auxiliary Doppler observation /31 station will be analyzed. The totality of these studies will be made jointly by the Meudon Observatory (measuring and reduction of the negatives, and computations) and by the Bureau of Longitudes (processing of the Doppler data and computations). The computation methods, scheduled by these two establishments, differ somewhat (analytical expression and numerical integration), so that the results will be twice verifiable.

The IGN and the Bureau of Longitudes are specifically interested in a verification of the triangulation data that could be obtained. Once the trajectory of the satellite is defined, an attempt will be made to fix the position of a given station from orbital data and from the position of two other stations.

The Meudon Observatory and the Bureau of Longitudes will attempt to determine, over a long period of time (several months), the variations in the orbital parameters and to derive from these data the deformations suffered by the satellite orbit. Also scheduled is the construction of a chart of the earth's gravitational field for the regions covered by the satellite and, from this, to define the position of the center of the earth relative to the stations.

VII. THE INSTRUMENT CAPSULE

All measurements that will yield data on the operation of the third stage of the launch vehicle and on all operations of the satellite, that must be either automatically fed in or preset before insertion into orbit, will be made by electronic equipment not carried on board the satellite but placed in a special capsule which connects the third stage of the launch vehicle with the satellite and which will separate from the satellite 13 min after liftoff. This instrument capsule is also provided with a radar responsor which operates in connection with the Aquitaine radar, erected at the Hammaguir Base, permitting position-fixing of the satellite so long as this is not yet separated from the capsule, including the first approximate orbit determination.

Thus, this module which weighs as much as the satellite (19 kg), has /32 three principal missions:

Data collection on operation of the third stage of the launch vehicle; the capsule is equipped with its own telemetering system (5 channels).

Chronological distribution of the commands to certain satellite equipment and control of the commanded operations during the phase of orbit insertion; for this purpose, the capsule carries an electronic programer.

Position-fixing of the space vehicle; for this, the module is equipped with a radar responsor.

This capsule, like the satellite, has been designed to withstand the rigorous environmental conditions to which it will be subject from the moment of liftoff. The capsule testing was similar to the satellite testing, using the above-described method; only the long-term vacuum tests were omitted, since the capsule is not intended for prolonged operation in space environment.

7.1 Structure of the Capsule

The capsule, weighing 8 kg, forms a mechanical link between the third stage of the launch vehicle and the satellite itself. Basically, it consists of two parts:

A truncated cone of magnesium alloy, attached to a collar that serves as mechanical support for the satellite and transmits the thrust of the launch vehicle to it. On its upper portion, this truncated cone carries the system of separation from the satellite, including the separation strip, an ejection spring, and a device for measuring the separation velocity. The lower portion is provided with the yo-yo mechanism for decelerating the rotation of the total assembly formed of third stage, instrument case, and satellite.

A platform composed of a collar attached to the forward skirt of the third stage and a base made integral with the collar by a plaited Nylon thread lacing. This lacing suppresses practically all vibration effects at frequencies above 30 cps. To the upper and lower faces of this base, various pieces of equipment, as well as the cables and electric wires are mounted.

7.2 Power Supply /33

The various pieces of equipment of the capsule are fed by three groups of batteries and one static converter, comprising:

A silver-zinc battery feeds all instruments, except the pyrotechnic circuits and the timing mechanisms.

Four batteries are used for feeding the pyrotechnic circuits that control the opening of the nose cone, jettisoning of the yo-yo, deployment of the satellite panels, and separation of the satellite from the capsule.

Two batteries autonomously feed the two automatic timers of the capsule.

7.3 Telemetry System

The five-channel telemetering equipment of the FM/FM "Ajax" type operates from liftoff of the launch vehicle until separation of the third stage, beyond the down-range station in the Republic of Lebanon. Consequently, the equipment transmits all data on the third stage of the launch vehicle, the angular velocities, and the accelerations of the system formed by third stage, capsule, and satellite, as well as the temperatures of the instruments in the capsule and the voltages at the terminals of the various circuits; other data are obtained on the start of the automatic timers and on execution of the commands given by the latter.

More exactly, this equipment transmits the following data:

On the first channel, data on the axial acceleration, furnished by the accelerometer.

On the second channel, data on the angular velocity in yaw, furnished by one of the three gyrometers placed in the box housing the accelerometer.

On the third channel, data on the angular velocity in pitch, furnished by the second gyrometer.

On the fourth channel, data on the pressure in the propulsive unit of the third stage.

On the fifth channel, 28 measurands in all: In fact, this channel it- /34 self is submultiplexed in PAM (pulse-amplitude modulation). The sequential sampling is done in the rhythm of 75 per sec, using 30 subchannels. Thus, the following are transmitted: two pressure data in the chamber of the third stage; temperature of the gyrometer unit (which is thermostated during the countdown phase at the ground, after which heatinsulated enclosures maintain the established equilibrium); temperature of the telemetering unit; temperature of the radar responsor and the battery; feed voltage of the pickups, detectors, and timers, etc. In addition, the PAM channel controls the commands given by the programer as well as the execution of these commands.

The transistorized transmitter radiates a power of 2 w and transmits on a frequency of 252 mc. The communication range, under reliable reception conditions, is more than 2300 km for the Hammaguir station and 1400 km for the down-range station in Lebanon.

The two quarter-wave antennas are staggered by 90°, on the cone of the instrument capsule. Each antenna is bent through 90°, to permit transmission during the time that the nose cone of the third stage still surrounds capsule and satellite.

7.4 Programer

The operations to be executed by the instrument capsule are started in sequence by two identical and independent electronic timers, operating in parallel and autonomously fed by two batteries.

7.5 Radar Responsor

To increase the tracking range of the Aquitaine radar, erected at the launching base at Hammaguir, the instrument capsule has been provided with a radar responsor matched to radar frequency (6000 mc, i.e., a wavelength of 5 cm). This radar responsor receives the emitted signals and re-emits them at an adjacent frequency, after amplification and shaping. The return signal received by the radar is thus much stronger than if the incident signal had been simply reflected from the outer surface of the capsule. This enables the Aquitaine radar to localize the capsule up to distances of 2000 and even 2500 km. The antennas of the responsor are mounted to the third stage of the launch ve- /35 hicle. Thus, the satellite can be localized by the radar only as long as it remains integral with the capsule and with the third stage of the Diamant. After its separation, the ground radar is used only for localizing the capsule and the third stage, which latter by then also has become a satellite. Therefore, the responsor is automatically stopped shortly after passage above the station of Beirut. The responsor is restarted by means of the onboard programer as soon as the unit of the third stage plus capsule reappears on the horizon west of Hammaguir.

VIII. LAUNCHING AND OPERATING SCHEDULE

The satellite D-1 will be launched from the Algerian base at Hammaguir, using the Diamant launch vehicle. The satellite will be placed in a nominal orbit of 506 km at perigee and 2650 km at apogee, inclined by 34° to the Equator. Operation of the satellite does not place any restrictions on the hour of launching.

8.1 The Diamant Launch Vehicle

This launch vehicle, whose first successful blastoff took place on November 26, 1965 and of which the scheduled launching will be the second, was manufactured under the management of the Society for Research and Development of Ballistic Rockets (SEREB), under the auspices of the Ministerial Delegation for Armament (DMA).

The vehicle has three stages, with the first using liquid propellants and the other two, solid propellants. The vehicle is the last of a series of "Precious Stones" vehicles manufactured by the SEREB, with the "Émeraude" constituting the first stage of the launch vehicle, the "Topaze" constituting the second stage, and the "Rubis" serving as basis of the third stage. The overall length of the Diamant is 19 m, at a total mass of 18.4 tons.

The two first stages are automatically piloted but not guided, i.e., the launch vehicle describes a nominal trajectory according to a program fixed in advance and stored in the onboard programer. The third stage is not automatically piloted but simply stabilized at a rotational velocity of 270 rpm about its longitudinal axis.

The first stage is controlled in yaw and pitch by means of a swivel nozzle. Control in roll is ensured by aerodynamic fins attached to the rear skirt of /36 the stage. The directional stability of the second stage is controlled by rotation of its four movable nozzles.

	1st Stage	2nd Stage	3rd Stage
Length (m)	9.99	4.71	1
Diameter (m)	1.4	0.8	0.65
Structural weight (kg) ..	1950 (steel)	670 (steel)	67.8 (glass fiber)
Weight of propellants (kg)	12,762	2260	641
Propellants	nitric acid and turpentine	Isolane powder	Isolane powder
Specific impulse (sec) ..	233	259	273
Combustion period (sec)..	93	44	45
Thrust (kN)	274	150	27-53

The third stage is first suitably aligned over an electronic balancing unit before being placed in rotation, after which it is fired. This balancing orients the stage in a direction that practically coincides with the local horizontal of the insertion point.

8.2 Preparation of the Launch Site and Launching

On arrival at the launch site, the instrument capsule and the satellite are first checked in a laboratory. At the instant of readying the Diamant, these two units are assembled and mounted to the top of the third stage of the launch vehicle.

From this moment on, the controls of the satellite proceed basically in two manners:

By umbilical cords, attached to the blockhouse near the launch emplacement; these cables carry the feeding currents which prevent unnecessary discharge of the batteries and permit certain check tests.

By telemetering from the capsule and the satellite, with the data received several kilometers away from the launch pad in a specially equipped trailer. This trailer truck contains two simplified telemetry receiving stations as well as simple switching means that permit a successive control of the main characteristics to be monitored. The entire unit is placed under automatic control /37 by a small computer, which executes the commands in succession and checks whether the results are well within the prescribed standards, and which is also used directly for making some computations. One of these mathematical operations is to convert the data arriving in the form of frequencies (the telemetering is coded by frequency modulation) into the corresponding physical quantity (volts, amperes, degrees).

This trailer and its console have tracked the satellite step by step during its integration and through all of its tests. A similar unit has been successfully used during the recent launching of the FR-1.

In the final seconds of countdown, the umbilical cord of the satellite is ejected; that of the instrument capsule falls away at the instant of liftoff of the launch vehicle.

The sequence of events then is as follows:

H* = 0	Firing of the first stage of the launch vehicle Diamant, which carries the satellite D-1 in its nose cone;
H + 94 sec	Burnout of the first stage and separation;
H + 95 sec	Firing of the second stage;
H + 139 sec	Burnout of the second stage;
H + 147 sec	Fallaway of the nose cone shielding the satellite;
H + 162 sec	Igniting of the balancing device; this operation takes 90 sec and places the vehicle parallel to the local horizontal of the point reached at the instant of firing the third stage;
H + 280 sec	Start of rotation at a velocity of 270 rpm;
H + 295 sec	Separation of the second and third stages;
H + 452 sec	Firing of the third stage;
H + 497 sec	Burnout of the third stage and orbit insertion;
H + 747 sec	Start of operations commanded by the instrument capsule: /38 jettisoning of the yo-yo; at this instant, the velocity of rotation is reduced to 35 rpm, cut-out of the radar responsor;
H + 767 sec	cut-in of the transmitters and start of the geodesy experiment, deployment of the solar panels;
H + 787 sec	Separation of the satellite D-1;
H + 1547 sec	Cut-out of operation of instrument capsule;
H + 6487 sec	Cut-in of the radar responsor.

* H = T-time.

8.3 Determination of the Initial Orbit

The Diamant, once fired, is followed by a large variety of tracking and telemetering facilities. The principal means used are given below:

Aquitaine radar, combined with a computer (CIEES)*.

Diane Station of Hammaguir (CNES).

Telemetry station (CIEES) with the large parabolic antenna "Cyclope" of 28 db gain. This station receives the second and third stage inter-stage telemetered data on the 245 mc band and the telemetered data of the instrument capsule on 252 mc; the station directly demultiplexes some of the channels to obtain immediate data on the operation of critical points of the rocket or of the satellite.

Iris station (CNES) which receives the telemetered data from the satellite on the 136 mc band and which also can demultiplex in real time certain parameters.

Tractor-trailer fully equipped with low-gain antennas, which permits tracking the satellite up to the radio horizon. This trailer also contains receivers (150 and 400 mc) that permit checking on the operation of the corresponding onboard equipment.

Telemetering station installed on board the Navy escort vessel "Guépratte", cruising in the Gulf of Gabès.

Iris Station (CNES) of Beirut. /39

Down-range station (CNES) of Beirut, equipped with a 12-db antenna for receiving data from the instrument capsule on 259 mc, with instantaneous decommutation, permitting a control in real time of proper execution of deployment and separation.

* CIEES = Interservice Testing Center for Special Rockets

Receivers on 150 and 400 mc and corresponding antennas, also installed near the CNES station in Lebanon.

In principle, the data of the Aquitaine radar, relative to the beginning of the ballistic phase which follows the insertion into orbit, permit determining the entire orbit. The accuracy is greater the greater the tracked length of the trajectory element. The radar data thus represent the basic data from which the predictions for orbiting are made. To guard against the risk of computer failure, the data of the Aquitaine radar are transmitted by radioteletype to the computer center at Brétigny which thus performs the same computations independently. The two computer centers have highly refined programs available that are able to detect certain errors in the measurands that, for example, might be due to transmission, and thus to determine the confidence level for the obtained results. If the data furnished by the Aquitaine radar are not of a sufficiently good quality, data on the Doppler effect (radial velocity) can be introduced into the programs, as furnished by the Iris station at Hammaguir, followed by the Doppler data from the Iris station at Beirut and the precision Doppler data obtained, again at Beirut, on 150 and 400 mc.

All launch operations are under the auspices of CIEES, assisted by the CNES over its Computer Center and its Operation Center at Brétigny. From the moment of orbit insertion of the satellite, the CNES takes over the responsibility of position fixing and communications with the satellite.

8.4 The Satellite in Orbit

We will only give the basic principles of the organization of operations, since this is more or less the same for all satellites.

8.4.1 The tracking means, permitting an accurate determination of the position of the /40 satellite at a given instant, consist of the Diane network comprising two stations, one at Hammaguir and one at Prétoria. These stations are based on the principle of radio interferometry. As a function of time, they furnish highly accurate data on the direction of the satellite relative to the station. These data, combined with theoretical considerations of celestial mechanics that rule the motion of the satellite, permit a step-by-step improvement in the definition of the orbital parameters.

8.4.2 <u>The telemetering means</u> comprise the Iris stations installed at Hammaguir, Ouagadougou, Brazzaville, Prétoria, and Beirut. The station at Brétigny will also be used, but the satellite does not overfly this station directly, and thus it is not certain that useful data can be obtained. These stations are all under the management of the Center of Operations at Brétigny which transmits to them the predictions of passage and the measurements to be made over the telex system. Each station records the telemetry signal as well as precision time signals. In certain cases, direct visual control is possible, yielding an approximate measurement of certain parameters, such as - for example - the voltage of the battery whose monitoring requires extreme care. In all cases, the recorded tapes are routed over commercial lines to the data processing center at Brétigny.

8.4.3 <u>The remote control operations</u> are organized in the same manner, except that only two stations can execute the remote-control commands for the D-1 satellite. These stations are Hammaguir and Prétoria. The satellite is so laid out as to transmit, on the average, one remote-controlled emission per orbit.

IX. DATA PROCESSING

On arrival of the tape recordings by aircraft at the Brétigny Center, they are re-assembled and checked at the Operations Center and then transmitted to the data processing center. The tape with scientific data (Doppler effect) will be processed by personnel responsible for the scientific experiment, while those having to do with operation of the launch vehicle (telemetry of the instrument capsule) will be worked up by the SEREB. /41

These processing operations consist in converting the coded messages, transmitted by the satellite or by the capsule, into numerical information. These digital data can then be processed directly on a computer which can also be used for analyzing the data.

The content of the magnetic tapes is distributed over seven tracks, since the telemetering data of the D-1 satellite are recorded three times.

9.1 The data processing center has the function not only of converting the analog recordings of the telemetered data into digital data that can be used directly by the computer but also of correcting any defects that were introduced from the modulation on board the satellite to the recording at the ground. This Center is equipped with numerous apparatus since each satellite has its own telemetering equipment, and a processing console is required for each type of telemetered data (PAM/FM telemetry of the satellite FR-1 used also for the instrument capsule, and PFM telemetry for the satellites D-1).

9.2 The computer center will be charged with processing all numerical tapes of telemetering and position fixing. This Center is equipped with IBM 7040 and 1401 computers.

Since 1964, a certain number of programs are underway for developing processing methods of satellite data, either of the telemetering or position-fixing types. Specifically, four mathematical programs were established for satellite tracking:

The program of initial orbit determination, based on data furnished by the radar of the launch site, permits a preliminary evaluation of the point of orbit insertion and diagnostics of satellite separation.

The program of differential correction of the insertion parameters processes the data collected during the first orbits (interferometer measurements, optical measurements, Doppler curve) and permits a better definition of the point of orbit insertion.

The program of differential correction of the orbital parameters, /42
based on measurements made by the interferometer stations over a period of eight days, permits an accurate reconstruction of the satellite trajectory. In fact, a precise determination of the satellite orbit is done in several stages: The theoretical orbit, calculated in advance and permitting an approximate prediction of the satellite passage above the stations, is first corrected by means of measurements made during the initial phase of orbital flight. However, a much greater accuracy is obtained by adjusting the values measured by the interferometers to this first approximation. This will greatly improve the quality of the ephemerides; after a period of several days, there is no further need to take measurements during all passages; however, the orbit which deforms in time is constantly monitored.

The program of local ephemerides, for an observation station, yields the coordinates and time of passage of the satellite over the other stations.

Thus, these preliminary studies of the Computer Center, combined with the development of data processing of the onboard measurements, should rapidly yield accurate information on the trajectory of the satellite as well as on its operation in space.

X. CHARACTERISTICS OF THE D-1A SATELLITE

	Weight (gm)
<u>Structure</u>	7132
Cylinder: honeycomb aluminum structure with sheet magnesium skin	
Cap and base: magnesium	
Supporting panels of solar cells: aluminum	
Antennas: aluminum	
Aluminum alloy, 52%	
Magnesium alloy, 39%	
Titanium, 2%	
Steel, 2%	
<u>Cables</u> (connections and wires)	1200
<u>Coatings</u>	
Gold	200
Paint	200
<u>Solar generator</u>	
2304 photovoltaic silicon cells, distributed over the two faces of the four panels	3065
<u>Battery</u>	
Eight nickel-cadmium elements, rated capacity 3.5 amp-hr	1941
<u>Modular equipment</u>*	
Telemetry transmitter (1; 720)	474
Telemetry encoder (3; 240)	372 336 331
Remote control receiver (1; 100)	569
Remote control decoder (1; off-power, 8 - interrogation, 12)	675

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* The numerals in parentheses represent the number of modules of the unit and the consumption (in mw).

		Weight (gm)
Converters	main (1), rated output, 66.7%	619
	secondary (1), rated output, 35.2%	339
Programer (1; in "stop" satellite, 34 - in "go", 69)		520
Onboard control measurements (1)		400
Transmitter for geodesy, operating on remote-control commands (1; less than 1100)		540
Charge monitor for battery (1)		352

<u>Nonmodular electronic equipment</u>

High-stability oscillator, consumption less than 500 mw

<u>All-up weight of the satellite: 19,270 gm</u>

XI. HISTORY OF THE D-1 PROGRAM

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May 9, 1962	Agreement signed between CNES and DMA for manufacture and testing of the satellite launch vehicle Diamant.
August 1962	Research and development contracts for solar cells.
December 1962	"Proposal for a satellite Diamant of 35 kg" (Satellite Division of the CNES).
1963	Studies of advance projects of the satellite.
April 20, 1963	Recommendation by the Scientific Committee of the CNES for building an experimental geodesy satellite.
July 1963	Contract for "instrument capsule". Contract for high-stability oscillator.
Sept. 18, 1963	Submission of the D-1 program to the launch-vehicle authorities, including structure and instrument capsule. Study of common problems.

December 1963	Specifications for the D-1 satellite. Contract for structure.
1964	Selection, ordering and receipt of the satellite equipment. Contracts let in April, May, and June. This equipment, designed by the Satellite Division of the CNES, was manufactured by French industrial firms either on the basis of an invitation to bid specifically for the D-1 (telemetry, geodesy transmitters) or in accordance with older submissions of proposals for the FR-1 satellite (remote control, converters, /45 programer). The batteries and the generator were ordered from the French firms that had studied and developed these pieces of equipment under a research contract by the CNES.
1965	Integration of the various satellite models, followed by qualification or reliability tests.
February 1965	Final assembly "on the drawing board".
April 1965	Research and development contract by the CNES-SEREB for adaptation of the Diamant launch vehicle elements to the satellites produced by the CNES.
June 5, 1965	Launching of the Rubis 01 rocket*, carrying the instrument capsule and a ballast mockup of the D-1 satellite.
Aug.-Sept., 1965	Integration of the flight model.

* See La Recherche Spatiale, Vol.IV, No.8-9, p.13.

September 1965	Launching of the Rubis 02 rocket*, carrying a second instrument capsule and a radioastronomy experimental capsule.
October 1965	Compatibility tests of satellite and launch vehicle at the Finalizing Center for Propulsive Units and Rockets (CAPE) of Saint-Médard (Gironde).
Oct.-Nov., 1965	Tests of the flight model.
November 26, 1965	Launching of the A-1 experimental capsule, carried by the first Diamant**.
February 1966	Launching of the D-1A.

XII. LIST OF PROJECT CONTRACTORS /46

Instrument capsule

Management, structure, tests, test bed	Électronique Marcel Dassault, E.M.D., 55, quai Carnot, (92) Saint-Cloud
Casting of the main parts in magnesium	Messier, (64) Arudy
Instrument capsule with three gyrometers and one accelerometer	Société d'Applications Générales d'Électricité et de Mécanique, SAGEM, 6, av. d'Iéna, Paris 16e
Springs	Bonatre, 9, rue des Longues-Raies, (92) Puteaux
Magnetokinemometer and	C.R.A.M., 8, rue Jean Moulin, (95)

* See La Recherche Spatiale, Vol.IV, No.11, p.53.

** See La Recherche Spatiale, Vol.V, No.1, p.11.

mechanical timers	Argenteuil
Yo-yo and various magnesium sheetings	Études et Constructions Aéronautiques, ECA, 304, av. d'Argenteuil, (92) Asnières
Satellite	
Structure, panels for solar cells and antennas	Engins Matra, 27, quai de Boulogne, (92) Boulogne-sur-Seine
Solar panels, honeycomb, platform for equipment and ferrule	Société Bréguet, B.P. 12, (92) Velizy-Villacoublay
Protection of parts	Société Vauriac, 121, av. Roche, (92) Gennevilliers /47
Thrust bearings for panels	S.L.I.C., 110, rue Daguessaut, (92) Boulogne-Billancourt
Module and battery casings	C.T.L., 7, rue de l'Église, (91) Morangis
Solar generator (cells and assembly), experimental plate for solar cells	Société Anonyme de Télécommunications, SAT, 41, rue Cantagrel, Paris 13e
Nickel-cadmium batteries	Société des Accumulateurs Fixes et de Traction, SAFT, 156, av. de Metz, (93) Romainville
Battery charge monitor	Électronique Marcel Dassault, E.M.D., 55, quai Carnot, (92) Saint-Cloud
Converters	Compagnie Crouzet, (26) Valence

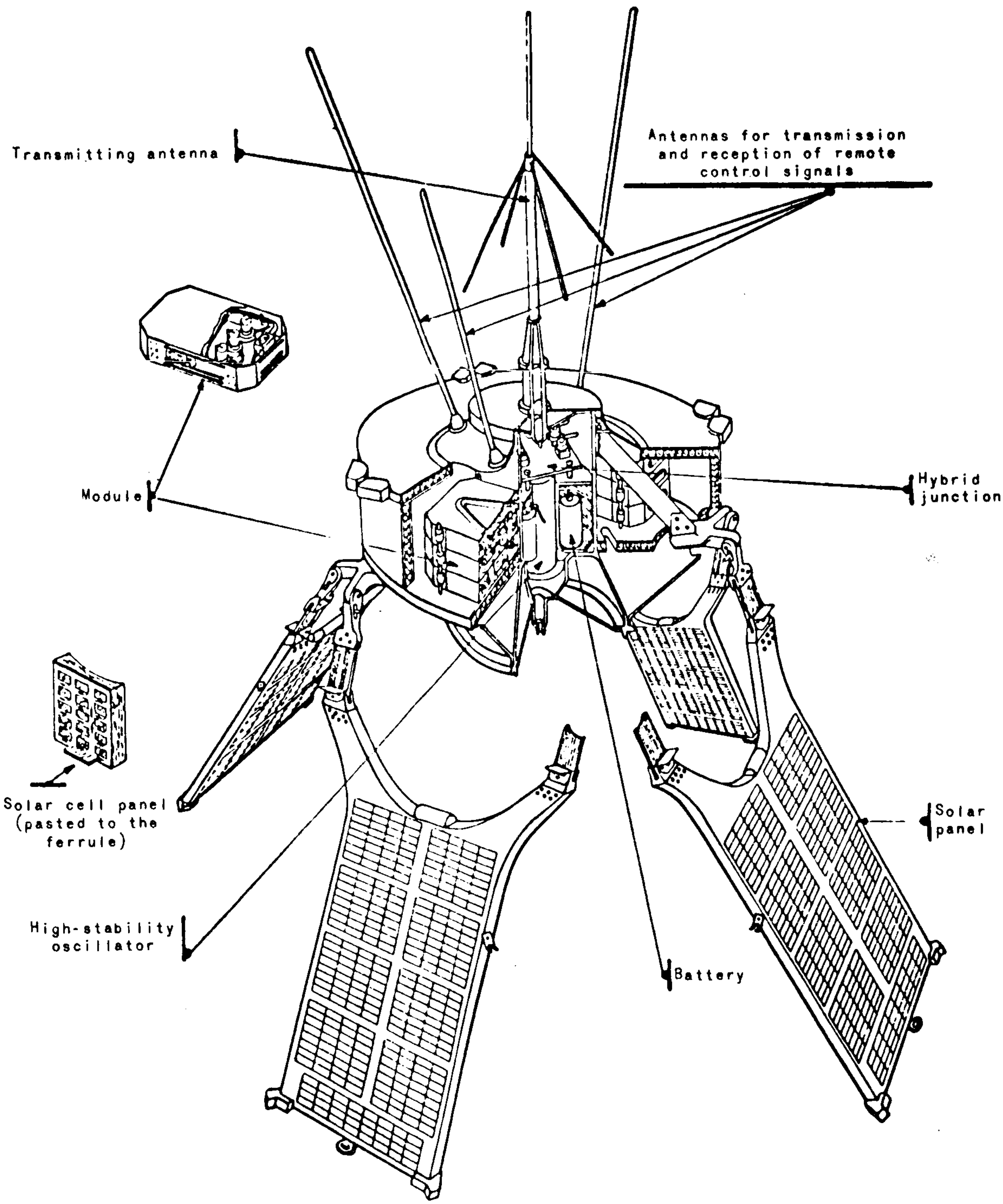
Programer, protection system for batteries	Compagnie Crouzet, (26) Valence
Telemetry transmitter	Société Sud-Aviation, Laboratoire de Physique Appliquée, L.P.A., 12, rue Pasteur, (92) Suresnes
Telemetry system (PFM encoder)	Société d'Instrumentation Schlumberger/Rochar Électronique, 42, rue Saint-Dominique, Paris 7e
Receiver and decoder for remote control	Compagnie Française Thomson-Houston, C.F.T.H., Division Radio-Télévision-Télécommunication R.T.T., (92) Gennevilliers
High-stability oscillator	Compagnie générale de télégraphie sans fil, C.S.F., Département de Piézo-électricité, (92) Courbevoie /48
150 and 400-mc transmitters for geodesic measurements	Compagnie générale de télégraphie sans fil, C.S.F., Domaine de Corbeville, (91) Orsay
Connection between capsule and satellite	Établissements F.R.B., 3, rue des Tilleuls, (92) Asnières
Thermal control coatings (heat shield)	Société des vernis Pyrolac, av. de Joinville, (94) Vitry-sur-Seine

Auxiliary equipment

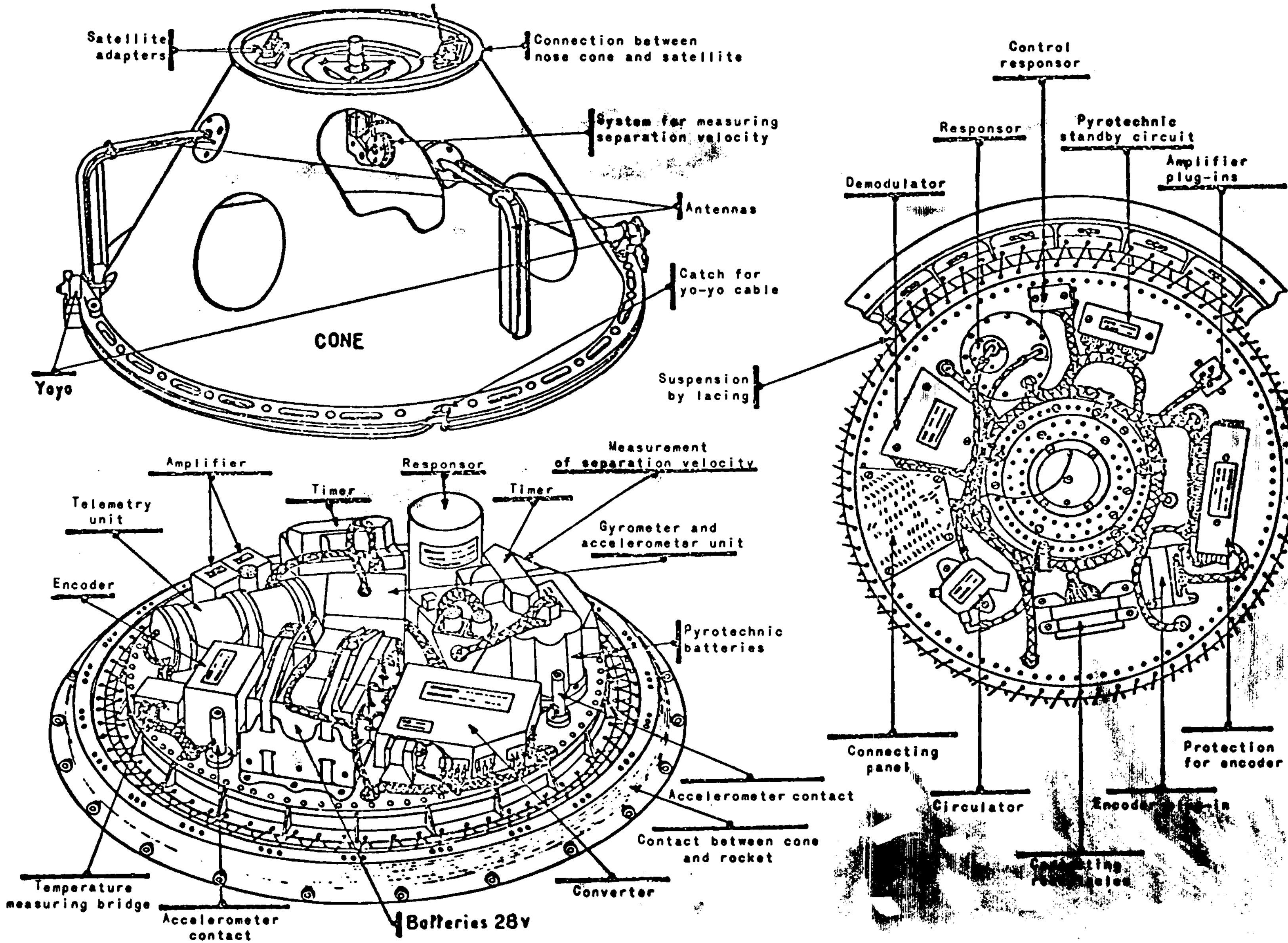
Automatic test bed	Compagnie des Compteurs, C.D.C., (92) Montrouge
Digital computer	Société Européenne pour le Traitement

	de l'Information, SETI, 100, route de Paris, (91) Massy
Antenna of trailer	Portenseigne, 82, rue Manin, Paris 19e
Trailer for test bed	Dorsey/Spair, 24, rue du Rocher, Paris 8e
Maintenance materiel for the satellite	Somateco, 58, av. Aristide Briand, (93) Gagny
Telemetry and remote control station, Iris	Compagnie générale de télégraphie sans fil, C.S.F., Parc du Château de Rocquencourt, B.P. No.2000, (78) Versailles
	ELECMA (Division Électronique de la SNECMA), 22, quai Galliéni, (92) Suresnes /49
	Nord-Aviation, 12 bis, Av. Bosquet, Paris 7e
	Compagnie Industrielle des Télécommunications, CIT, 33, rue Émeriau, Paris 15e
	Aéromaritime Électronique, 57, av. d'Iéna, Paris 16e
	AMPEX, 113, rue de l'Université, Paris 7e
	Société d'Études de Réalisation d'Exploitations Thermiques et

	Électriques, SERETE, 164, rue de Rivoli, Paris 1er
	Société Générale d'Exploitation Industrielle, SOGEI, 4, rue d'Aguesseau, Paris 8e
	Société d'entreprises générales et électroniques, SONECTRO, 27, rue de Marignan, Paris 8e
Doppler receiver (Lebanon Station)	
- 150 mc	Compagnie générale de télégraphie sans fil, C.S.F., Domaine de Corbeville, (91) Orsay
- 400 mc	Société Sud-Aviation, Laboratoire de Physique Appliquée, L.P.A., 12, rue Pasteur, (92) Suresnes
Diane tracking stations	Compagnie Française Thomson-Houston,/50 C.F.T.H., 173, Blvd. Haussmann, Paris 8e
	Société Technique d'Applications et de Recherches Électroniques, STAREC, 12-14, av. Carnot, (91) Massy
Space simulator	Société d'Études et d'Applications Vide Optique Mécanique, SEAVOM, 30, rue Raspail (95) Argenteuil



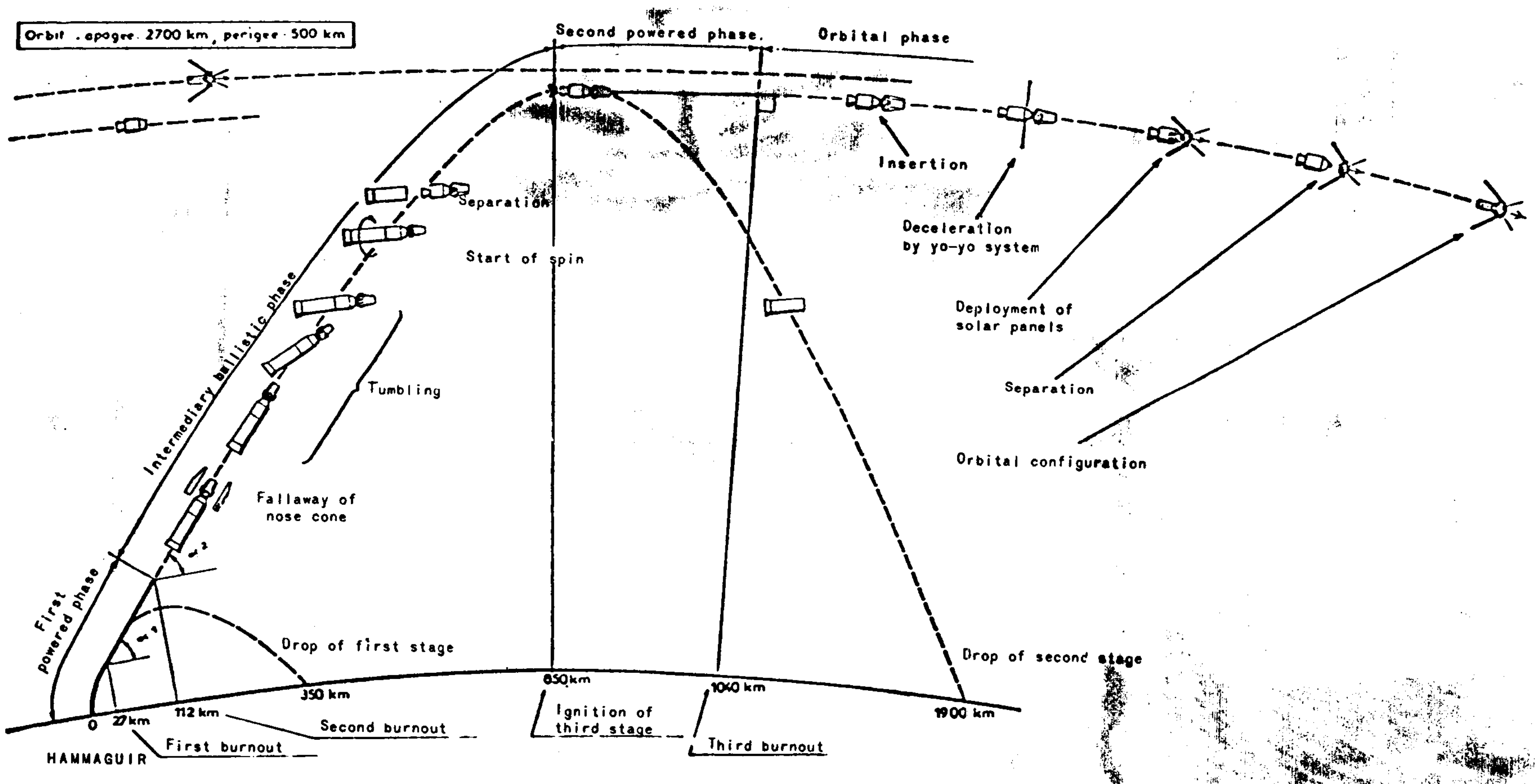
Satellite D-1A.



TOP OF PLATFORM

BOTTOM OF PLATFORM

Instrument Capsule



Schematic Diagram of Launching and Insertion into Orbit

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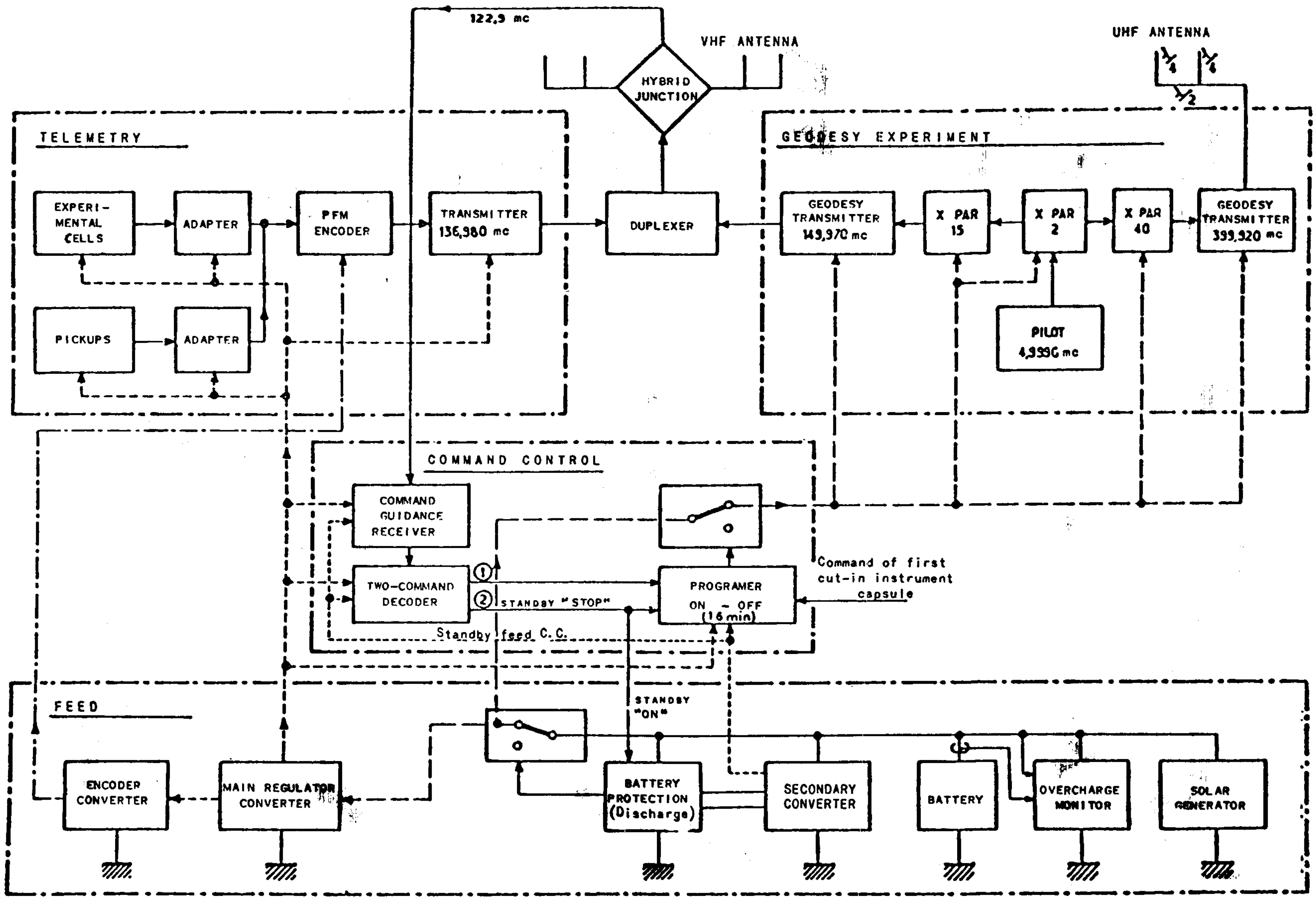
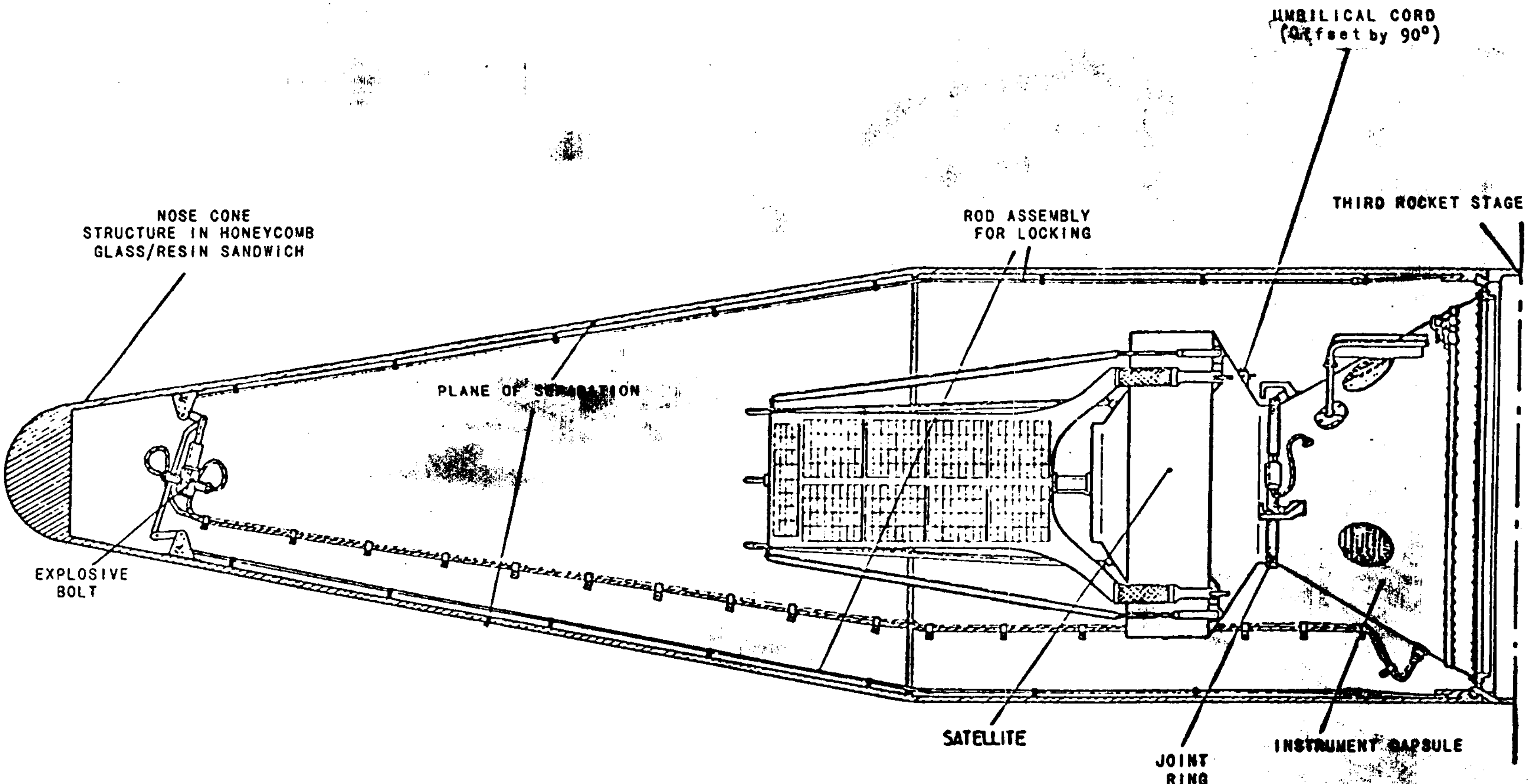


Diagram of the satellite.



The satellite in the nose cone of the Diamant Launch vehicle.

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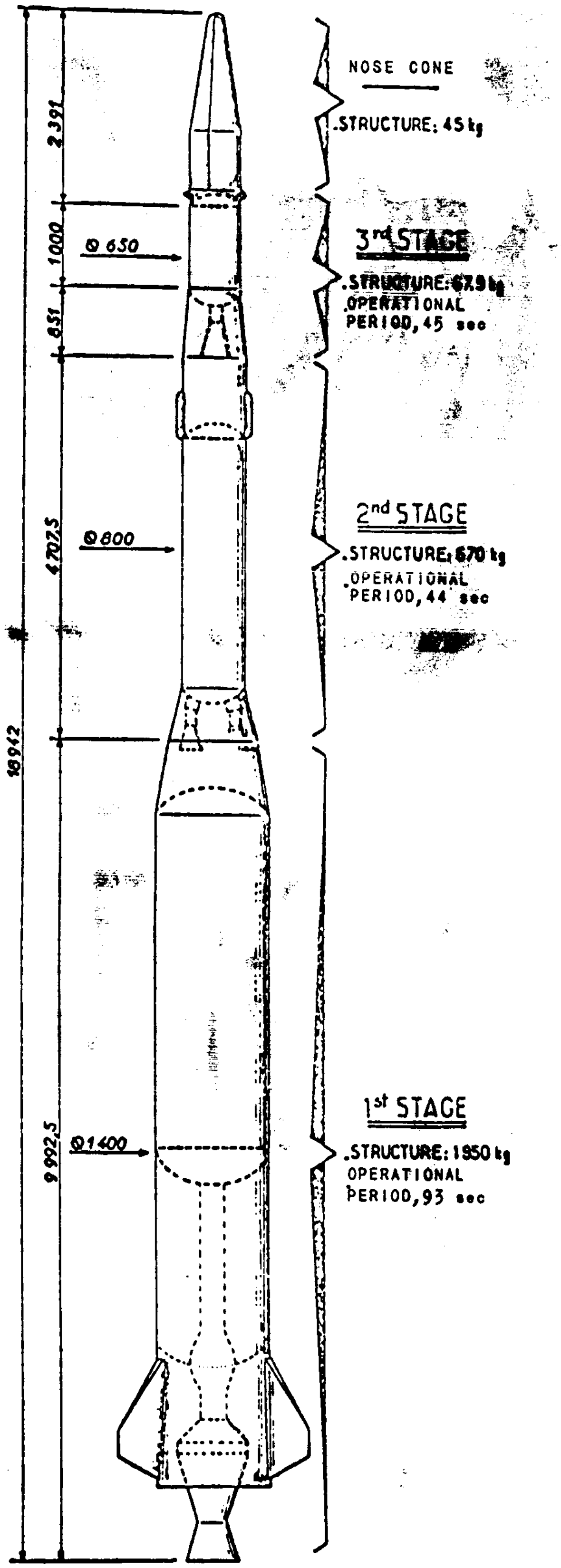
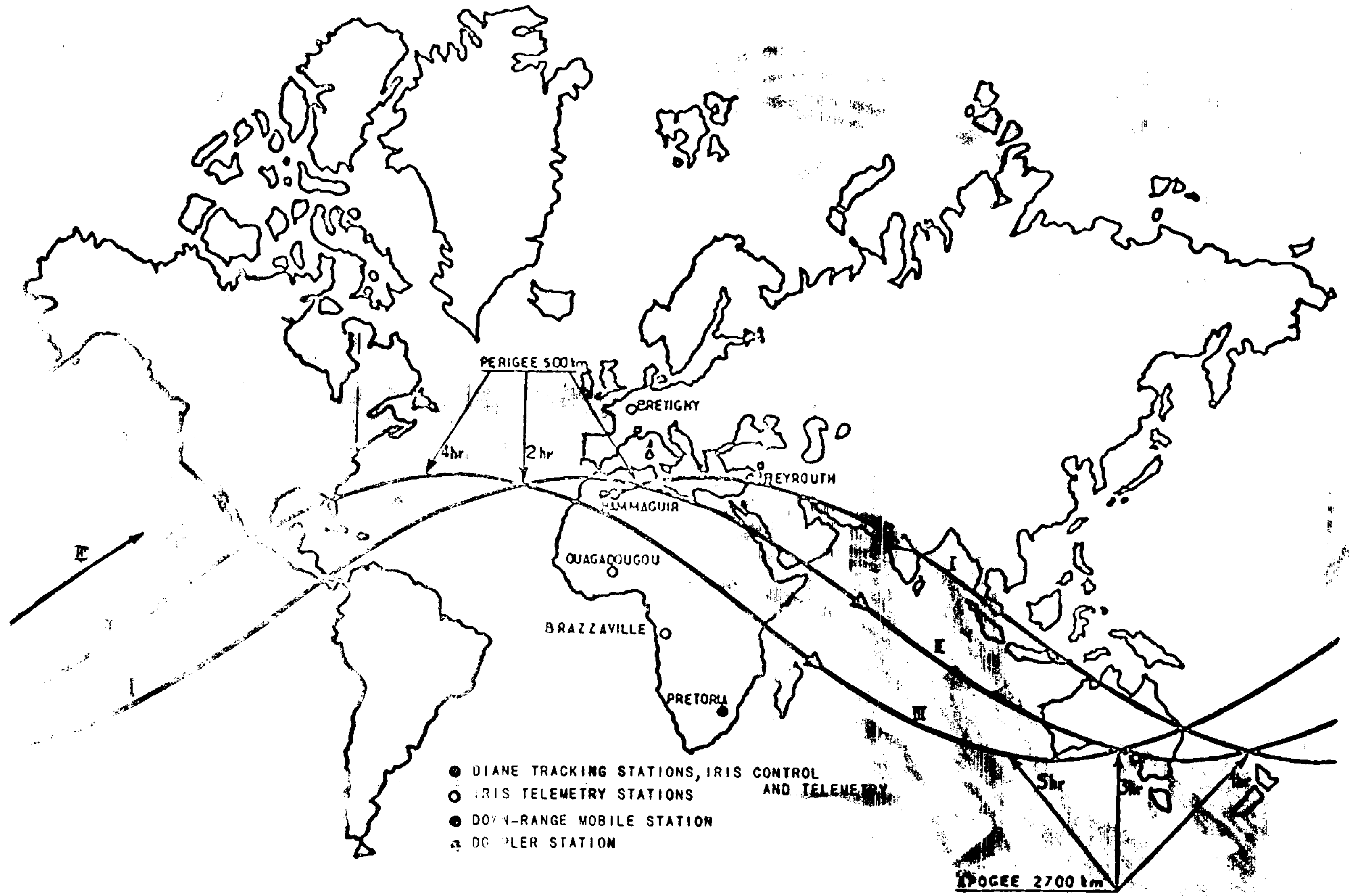


DIAMANT
LAUNCH VEHICLE



First Orbits